

BOUNDARY SCAN WITH STROBED PAD DRIVER ENABLE

Cross-reference to related applications

5 **[0001]** This application claims the benefit of United States Provisional Patent Application Serial No. 60/425,994 filed November 14, 2002.

BACKGROUND OF THE INVENTION

Field of the Invention

10 **[0002]** The present invention relates, in general, to the testing of integrated circuits (ICs) and, more specifically, to a method and circuit for testing integrated circuit (IC) output pin circuitry, and connections between pins of ICs on circuit boards.

Description of Related Art

15 **[0003]** A common way to provide test access to digital pin signals of an IC is to implement digital boundary scan according to the rules defined in the "IEEE Standard Test Access Port and Boundary-Scan Architecture", published in 1990 and 2001, by the Institute for Electrical and Electronic Engineers (IEEE), which is also known as IEEE Std. 1149.1-2001, or simply 1149.1. A dominant
20 characteristic of 1149.1 is the use of a test access port (TAP) controller that has a prescribed state diagram, an Instruction Register (IR), and multiple Data Registers (DR), one of which is the Boundary Scan Register (BSR). **FIG. 5** is a state diagram which shows all possible states of an 1149.1 TAP controller.

25 **[0004]** Note that bond pads of a bare integrated circuit die are eventually connected to the pins of an encapsulating package. Accordingly, in the present disclosure, the terms "pin", "bond pad" and "pad" will be used interchangeably.

30 **[0005]** Recently, 1149.1 has been shown to be suitable for facilitating reduced pin-count testing of high pin-count ICs, which can significantly reduce the cost of testing the ICs. To enable this method, pin circuitry is first made bi-directional by the provision of input buffers **11** and output drivers **15** connected to bond pad **17**, as shown in **FIG. 1**, and then boundary scan circuitry is added, as shown in **FIG. 2**. The boundary scan circuitry includes a shift register element **19** for testing the enable input of output driver **15**, and a shift register element **21** for testing the data input of driver **15**. Register element **21** includes a storage register (not

shown) for storing an output data value and/or a captured data value. Output driver 15 is enabled by an enable bit stored in register element 19. The output data value and/or captured data value is stored in the storage register in register element 21. To permit implementation of a HIGHZ instruction defined by 1149.1, a slight modification is needed for the BSR-controlled pad driver circuitry 30 of FIG. 3, to facilitate simultaneously tristating (disabling) all output drivers. The modification comprises an AND gate 23 which receives the output of register 19 and an inverted **forceDisable** (tristating) signal. Thus, when the **forceDisable** signal is inactive (logic 0), the state of the enable input of output driver 15 is determined by the output of register 19. An active **forceDisable** signal is applied to override the output of the shift register.

[0006] Applicant's United States Patent Application Serial No. 09/570,412 filed May 12, 2000, for "Method and Circuit for Testing D.C. Parameters of Circuit Input and Output Nodes" (Applicant's Docket LVPAT017US), now Patent No. 6,586,921 B1 granted on July 1, 2003, incorporated herein by reference, discloses a method by which the simultaneous tristate function is tested for unconnected pins of an IC using the timing shown in FIG. 4. In that method, at time t_1 , the pins are tri-stated in response to an instruction being loaded into the IC. Subsequently, at time t_D , the data input to the output drivers is changed. Then, at time t_2 , the logic value of the pad is captured. If the logic value changed in response to the data input change, then the tristate functionality is defective (for example, **forceDisable** is stuck at 0), and the chip fails the test. The sequence of states shown in FIG. 4 is in accordance with 1149.1. This test does not, however, test whether the Enable bit in the BSR is stuck on (due to a defect).

[0007] To test circuit boards that contain ICs constructed according to 1149.1, different patterns of output driver logic values are shifted into the ICs during the Shift-DR state (the state is re-entered once per bit until all boundary scan bits have been shifted into all ICs), and the resultant logic value on each I/O interconnect is captured during the Capture-DR state. Then, another set of values is shifted in during the next transit through the Shift-DR state.

[0008] One problem with this test approach is that the minimum duration of the logic value of each output pin during testing is limited by the time required to reload the boundary scan register. For example, if ten ICs, each with a 100 bit boundary scan chain, are connected in series, then the time to reload the scan chain is one thousand periods of the test clock TCK during the Shift-DR state of the TAP

(see FIG. 5). If the clock period is the typical value of one microsecond, then the minimal time to reload the scan chain is one millisecond. Although this is a short time compared to total test time, any high powered pin drivers that are short-circuited for that duration of time may be damaged by the heat generated within its transistors while the abnormally high current is flowing. In some cases, damage can occur in tens of microseconds, and is sufficient to reduce the expected lifetime of the circuit.

[0009] Whetsel United States Patent No. 5,706,296 granted on January 6, 1998 for "Bi-directional Scan Design with Memory and Latching Circuitry" proposes a solution to this problem. The proposal includes providing a latching action in the output driver path so that a short circuit causes the driver to stop driving its intended logic value and switches to driving the opposite logic value. This approach requires modifying the driver's circuitry, to insert a delay in the output path, and may flip the driver's state if a very low impedance load is connected that is within specification.

[0010] Terayama United States Patent No. 5,736,849 granted on April 7, 1998 for " Semiconductor Device and Test Method for Connection Between Semiconductor Devices" proposes a solution which provides a weak output driver and a strong driver connected in parallel. During test mode, only the weak driver is enabled. As with the Whetsel solution, this circuit requires modification of the driver circuitry, and may not be able to drive a very low impedance load that is within specification.

SUMMARY OF THE INVENTION

[0011] The present invention seeks to provide a circuit and a method for testing the function of BSR bits that control the enable input to a driver of unconnected I/O pins of an 1149.1-compliant IC during the IC's reduced pin-count access manufacturing test, and to test the connections to these pins during the test of a circuit board containing the IC, without causing excessive current if a pin is inadvertently short circuited when pin drivers are enabled – the excess current being due to a defect or to too many outputs being enabled simultaneously.

[0012] The circuit of the present invention is constructed according to 1149.1, and comprises an IC having a first test mode in which data can be loaded into a BSR without updating the output latches, and a second test mode in which the BSR can be accessed and updated while output pin drivers of the IC are tristated, and circuitry to temporarily de-assert the signal that tristates the pin drivers, at the

time that the pins' logic values are captured by the BSR. "Temporarily" means a clock cycle or less and for only a portion of the capture-DR state.

5 [0013] The circuit aspect of the present invention is generally defined as a boundary scan interface circuit for use with a test access port (TAP) controller for testing the state of pin drivers of an IEEE 1149.1-compliant integrated circuit (IC) having a boundary scan register, the interface circuit comprising a tristate control circuit for selectively controlling the pin driver enable input of the pin drivers and responsive to a control input for temporarily de-asserting a signal that tri-states the pin drivers during a capture cycle of the TAP in which pin logic values are captured
10 by the BSR.

[0014] The method of the present invention tests that the enable bit path is not stuck in an 'on' state for unconnected pins during reduced pin-count tests of an IC by driving the pins to a selected logic state, then re-loading the BSR with the opposite enable values and opposite data values, simultaneously tristating all pins
15 before updating the outputs, de-asserting the tristate function and capturing the pin logic values while the tristate function is de-asserted.

[0015] One embodiment of the method of the present invention is generally defined as a method of testing an integrated circuit to test that boundary scan register pin enable bit paths are not stuck in an "on" state, the method comprising:
20 loading desired circuit pin data and pin driver enable data into a boundary scan register and updating the boundary scan register; loading opposite circuit pin data and the opposite pin driver enable data into the boundary scan register and suppressing updating of the register during a following register update cycle; forcing output drivers into a high impedance state (tristate); updating the data and enable
25 inputs to the output drivers to the said opposite logic values during one of a Run-test/idle or a Select-DR state of a test access port; capturing register outputs; and unloading and comparing captured outputs with expected outputs to determine whether any pin enable bit path is stuck in an "on" state.

[0016] Another embodiment of the method of the present invention is
30 generally defined as a method of testing an integrated circuit having a boundary scan register to determine whether circuit output pins have any short circuits between the pins and a power rail, or other high-current output, that might result in the flow of excess current, the method comprising: tristating circuit output pins; loading the boundary scan register with values to force output drivers into desired

output states; capturing pin outputs while de-asserting tristating during a capture cycle; and unloading captured data and comparing with expected values.

BRIEF DESCRIPTION OF THE DRAWINGS

5 **[0017]** These and other features of the invention will become more apparent from the following description in which reference is made to the appended drawings in which:

[0018] **FIG. 1** is a prior art schematic of a bi-directional pin of an IC.

[0019] **FIG. 2** is a prior art schematic of a bi-directional pin of an IC that has
10 BSR access to and control of the pin.

[0020] **FIG. 3** is a prior art schematic of a bi-directional pin of an IC that has BSR access to and control of the pin, and a tri-stating signal that can simultaneously tristate all such pin outputs.

[0021] **FIG. 4** is a set of waveforms for the circuit of **FIG. 3** when a prior art
15 method is used for testing the tristating signal when the pins are not connected directly to a tester.

[0022] **FIG. 5** is a prior art state diagram of the 1149.1 TAP controller.

[0023] **FIG. 6** is a schematic of a circuit according to one embodiment of the present invention.

20 **[0024]** **FIG. 7** shows waveforms of the circuit of **FIG. 6** when the circuit is used to test the tristate signal according to an embodiment of the method of the present invention.

[0025] **FIG. 8** shows alternative waveforms of the circuit of **FIG. 6** when the circuit is used to test the tristate signal according to another embodiment of the
25 method of the present invention.

[0026] **FIG. 9** shows waveforms of the circuit of **FIG. 6** when the circuit is used to test connections to the output driver according to another embodiment of the method of the present invention.

[0027] **FIG. 10** is a flow chart illustrating a test method for testing the function
30 of an enable bit of a pin driver, according to an embodiment of the present invention.

[0028] **FIG. 11** is a flow chart illustrating a test method for testing whether output pins of an IC, that is soldered onto a circuit board, has any short circuits between the pins and a power rail, or other high-current output, that might result in the flow of excess current.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0029] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the present invention,

5 However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well known methods, procedures, components and circuits have not been described in detail so as not to obscure aspects of the present invention.

[0030] The circuit of FIG. 6 shows the BSR-controlled pad driver circuitry 30 of FIG. 3 connected to a TAP controller 40 similar to the example TAP controller shown in the 1149.1 standard. The TAP controller typically outputs *ShiftDR*, *Mode*, *ClockDR*, and *UpdateDR* signals to control the boundary scan cells which form boundary scan register 42. Additional TAP controller outputs include *forceDisable*, which may be the logic value of a bit in the Instruction Register, *Capture-DR* which indicates when the TAP controller is in its Capture-DR state, inverted test clock, \overline{TCK} ; and *RTI*, which is active (logic 1) when the TAP controller is in the Run-Test/Idle (RTI) state. Many or all of these signals already exist in some TAP controller designs.

[0031] The circuit of the present invention is responsive to two more control signals provided by two register bits, Q_0 and Q_1 , which may be part of the TAP instruction register (IR) or part of a data register (DR), but preferably not the BSR. The bits are shown as isolated single-bit registers in FIG. 6 to indicate this generality.

[0032] The Q_1 bit is a tristate disabling control signal which determines whether the *forceDisable* signal is to be de-asserted during a TAP Capture-DR controller state. The Q_0 bit is an update selector control signal which determines whether update of the BSR is to be delayed, as explained below.

[0033] The two bits define two test modes according to the present invention. In a first test mode, both bits are active (logic 1). In the second mode, Q_1 is active and Q_0 is inactive (logic 0).

[0034] In both modes, the output driver tristating signal, *forceDisable*, is temporally de-asserted during BSR capture operations. In the first mode, the BSR normal update operation is suppressed or delayed until the next RTI state or

select-DR state of the TAP controller. In the second mode, normal update operations are performed during the Update-DR state of the TAP.

[0035] Referring to FIG. 6, the Q_1 bit is part of a first logic circuit 50 which includes a delay element Q_2 , in the form of a flip-flop 52, a NAND gate 54 and an AND gate 56.

[0036] The Q_1 bit is set to logic 1 to enable de-asserting of the *forceDisable* signal (i.e., forcing it to logic 0) during the TAP controller Capture-DR state when pin logic values are captured by the BSR. NAND gate 54 logically combines the Q_1 bit with a delayed Capture-DR state signal output by flip-flop 52. Thus, the output of NAND gate 54 is a pulse that is one test clock (TCK) period in duration and that is applied to one input of AND gate 56. AND gate 56 also receives the *forceDisable* signal and produces a modified *forceDisable* signal labeled *forceDisableBSR*. The Capture-DR signal is delayed by half of a TCK period so that capture occurs substantially in the middle of the clock period within which the tristating signal is de-asserted.

[0037] When the TAP controller is in a state other than the Capture-DR state, the output of NAND gate 54 is high (logic 1). The output of AND gate 56 then depends on the value of the *forceDisable* signal. When *forceDisable* is high, *forceDisableBSR* is high, the output of AND gate 23 is low and, thus, output driver 15 is tristated or disabled.

[0038] The Q_0 bit is part of a second logic circuit 60 which includes an AND gate 62 and multiplexer 64. When Q_0 is inactive (logic 0), normal update timing is selected (i.e., in accordance with 1149.1) by multiplexer 64, which outputs a signal labeled *UpdateBSR*. When Q_0 is logic 1, the multiplexer selects the output of AND gate 62 which is a delayed Update pulse which occurs during the RTI state. AND gate 62 logically combines the RTI signal and an inverted test clock signal, \overline{TCK} , to produce a pulse that is one half of one test clock period in duration.

FIRST TEST MODE

[0039] An objective of the present invention is to test that BSR Enable bit path 34 is not stuck in the "on" state. According to the method of the present invention, this is achieved by loading the BSR with pin data and pin driver enable logic values and updating pin outputs; configuring the circuit in the first test mode; 5 re-loading the BSR with data that would cause the output drivers to drive their opposite logic value and to tristate the output drivers, without updating BSR latches; applying an output driver tristating signal to tristate all pins simultaneously; updating BSR latches; and de-asserting the tristating signal, capturing pin logic values in the 10 BSR, and then re-asserting the tristating signal; and unloading the captured data for comparison with expected data.

[0040] Referring to FIG. 10, an embodiment of the method to accomplish this objective comprises:

[0041] Step 100 involves loading desired driver data and driver enable bits 15 into the BSR and updating the BSR so as to force output drivers to a known driving state such as, for example, driving logic 1 (while Enable is 'on').

[0042] Step 102 involves configuring the circuit in a first test mode by setting both register bits Q_1 and Q_0 to logic 1 which will suppress future updating of BSR latches during the Update-DR state of the TAP, cause future updating of the BSR to 20 occur during the RTI state of the TAP, and de-assert *forceDisable* during the Capture-DR state. This is achieved by either loading an instruction which includes bits Q_1 and Q_0 or loading an instruction which accesses a separate data register which includes bits Q_1 and Q_0 .

[0043] Step 104 involves reloading the BSR with data that would cause 25 output drivers to drive their opposite logic value and to tristate the outputs (Enable bit is 'off'). In this step, update of the BSR latches is suppressed because Q_0 was set active in step 102.

[0044] Step 106 involves loading an "EXTESTZ" instruction into the TAP controller instruction register. This instruction (whose name is arbitrary) is the same, 30 in its effect, as the standard EXTEST instruction that selects the BSR to be the active DR, and enables the BSR bits to control output drivers, except that the EXTESTZ instruction forces output drivers into their high impedance state (tristate) by an asserted *forceDisable* signal.

[0045] As shown by the waveforms of FIG. 7, the instruction register is updated with the EXTESTZ instruction at time t_1 , during the Update-IR state of the TAP, which tristates the outputs at time t_1 , shown by *forceDisableBSR* becoming active. It will be noted that the waveforms of FIG. 7 show only the timing-critical portion of the method.

[0046] Step 108 involves updating the Data and Enable inputs to the output drivers to opposite logic values during the RTI state. Alternatively, this update may occur during the Select-DR state, as shown in FIG. 8, so that the RTI state is not needed. The delay in performing the update is to ensure that the update of the Pad Data takes effect after the *forceDisable* signal becomes active.

[0047] Step 110 involves de-asserting *ForceDisable* during the Capture-DR state, preferably for one TCK cycle, and capturing the logic value of the pin signal by the BSR and shifting out the captured value for comparison with an expected value (logic 1 for this example).

[0048] Thus, if the pin enable path is stuck "on", then waveforms 115 -118 will occur and the wrong logic value (logic 0 in this example) will be shifted out, indicating that the related pin-driver was erroneously enabled, and so a defect must exist.

[0049] The above method may be repeated (step 112), but initially driving the pins to opposite starting values, e.g., to logic 0, instead of logic 1.

SECOND TEST MODE

[0050] The present invention also seeks to provide a method of testing whether output pins of an IC that is soldered onto a circuit board has any short circuits between the pins and a power rail, or other high-current output, that might result in the flow of excess current. This can be performed using the above described circuit. This embodiment of the method of the present invention generally comprises tristating the output drivers and then configuring the circuit in the second test mode; loading the boundary scan register with values to force output drivers into desired output states; capturing pin outputs while de-asserting tristating only during the capture cycle; and unloading captured data and comparing with expected values.

[0051] Referring to FIG. 11, this embodiment of the method is as follows.

[0052] Step 200 involves setting register bit Q_1 to logic 1, which de-asserts **forceDisable** during Capture-DR, and register bit Q_0 to logic 0, which enables normal BSR update operations during the TAP Update-DR state, and forces output drivers into their high impedance state (tristate) by an asserted **forceDisable** signal.
5 This is achieved by either loading an instruction for an instruction register that includes bits Q_1 and Q_0 or loading an instruction which accesses a separate data register which includes bits Q_1 and Q_0 .

[0053] Step 202 involves loading bits into the BSR to force output drivers into selected output states (when the **forceDisable** signal is de-asserted). When the
10 Update-DR pulse state occurs, as shown in FIG. 9, BSR latches are updated, but the output drivers remain in high impedance state (shown symbolically as a mid-rail dash-dot waveform 135) because of the active **forceDisable** signal.

[0054] Step 204 involves temporarily de-asserting the **forceDisable** signal during the next Capture-DR state, as shown in FIG. 9, causing the pins to be driven
15 to their intended output states, and capturing the resultant pin logic values in the BSR.

[0055] Step 206 involves unloading the captured bits for comparison to expected bit values. According to the 1149.1, new data values for subsequent tests may be shifted in simultaneously with shifting out captured values. Captured logic
20 values which differ from expected values indicate a short circuit.

[0056] The method of the present invention may be used for testing a circuit board that has a mixture of circuits, i.e., circuits which incorporate the interface circuit of the present invention and circuits which do not. The method does not require a change in the protocol used to access the BSR of any of the circuits.

[0057] In addition to shorts to power rail and high-current output of any circuit, the method allows safely detecting stuck enable bits in integrated circuits which do not implement the method of the present invention but which are connected to circuits which include the circuitry of the present invention. This type of fault might
25 be normally detected by standard 1149.1 boundary scan when a wire is driven simultaneously by a defect-free circuit and by a defective circuit that has its enable stuck "on"; however, if the defect-free circuit embodies the present invention, high current will flow for much less time and thus cause no damage to the defect-free circuit.
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[0058] Excess current may flow through a pin for other reasons, including
35 inadvertent mechanical connections between a wire and other metallic objects, or

due to shorts between wires that travel to other circuit substrates. Excess current may also flow through a power rail when too many output drivers are enabled simultaneously – the present invention greatly reduces the time interval during which the excess current flows, and hence reduces the average current.

- 5 **[0059]** Although the present invention has been described in detail with regard to preferred embodiments and drawings of the invention, it will be apparent to those skilled in the art that various adaptations, modifications and alterations may be accomplished without departing from the spirit and scope of the present invention. Accordingly, it is to be understood that the accompanying drawings as set forth
- 10 hereinabove are not intended to limit the breadth of the present invention, which should be inferred only from the following claims and their appropriately construed legal equivalents.